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B. M. Potts

Summary of Radiation Pattern Measurements Using the LES-7 Lens and Variable Power Dividing (VPD) Feed Network at 7.68 GHz

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FOR THE COMMANDER

Eugene C. Raabe

Eugene C. Raabe, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

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B. M. POTTS

Group 61

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ABSTRACT

A comparison between experimental and calculated radiation pattern data for a multiple-beam antenna is presented. The antenna consists of a waveguide lens aperture excited by a 19-element feed horn array and variable beam-forming network. The pattern data presented varies from a narrow high-gain beam, equivalent to that of a steerable paraboloid, to the earth-coverage pattern of a wide coverage communication satellite. Also discussed are the results of the earth-coverage measurements when either one or two feeds are turned off so as to produce nulls in the earth-coverage pattern.

Summary of Radiation Pattern Measurements Using the LES-7[1,2] Lens and Variable Power Dividing (VPD) Feed Network at 7.68 GHz

I. Introduction

A previous note [2] presented some characteristics of a communication satellite multiple-beam antenna. The lens for this antenna was built in a previous program [1]. The purpose of the present study was to gain experimental evidence on the operation of the lens antenna with an electronically-controlled beam-forming network, and to validate experimentally the predictions available from a detailed computer model of the antenna [3], so that this computer model could be used with greater confidence in design studies for satellite communication antennas. This report presents a summary of some of the radiation pattern and gain measurements on this antenna.

II. Antenna Geometry

The waveguide lens antenna is shown in Fig. 1. The lens is approximately 30 inches in diameter with a focal length equal to 30 inches. It is constructed from approximately 700 titanium waveguides each having a 1 x 1-inch cross section and a .005-inch wall thickness. The outer surface of the lens has been "stepped" or "zoned" so as to reduce the weight of the lens and increase its bandwidth; the inside surface of the lens is spherical with a radius of approximately 30 inches.

The lens is excited using a planar feed cluster with the center of the cluster lying along the lens axis and located 30 inches from the vertex of the lens. The feed cluster consists of 19 conical horns arranged on a triangular lattice (as illustrated in Fig. 2) with each feed horn having a diameter of

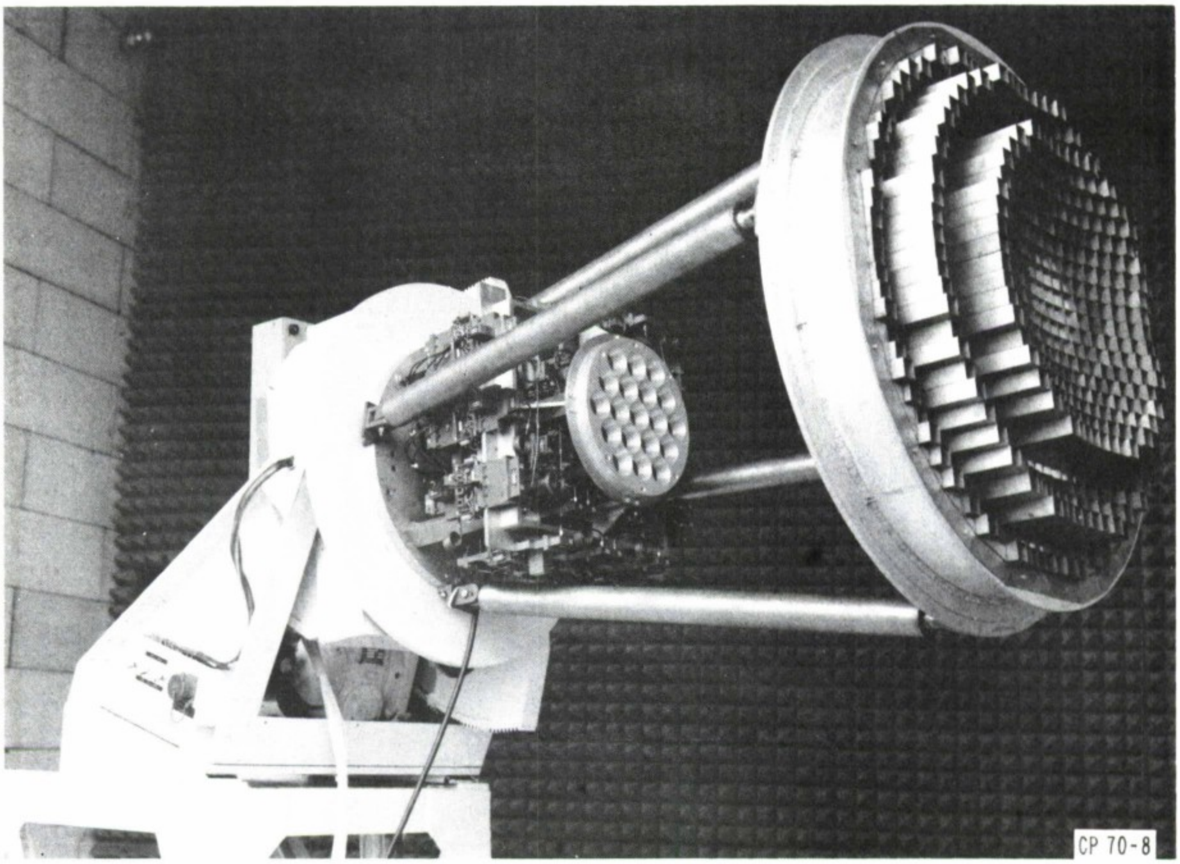

Fig. 1. Experimental multiple-beam lens antenna.

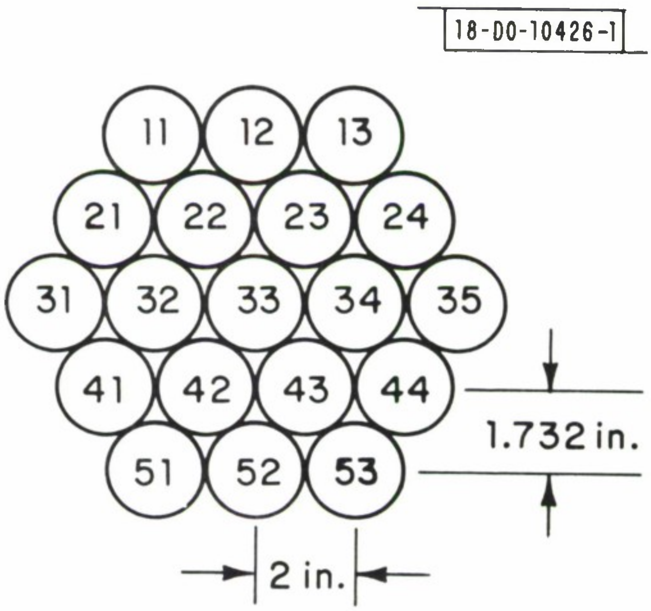

Fig. 2. Feed cluster geometry, indicating numbering scheme.

2.00 inches and a center-to-center spacing between horns equal to 2.00 inches. The horns are excited by a loop in a one-inch diameter waveguide so that each feed radiates a linearly polarized signal.

Directly behind and attached to the feed cluster is a square aluminum frame. Located around the edge of the frame are the 18 Variable Power Dividers (VPD's) which are interconnected to form the Beam-Forming Network (BFN). The purpose of the BFN (as described in more detail in Refs. 1 and 2) is to connect a single transmit or receive port to any combination of the 19-feed ports, in a completely flexible way. The VPD's are interconnected using semi-rigid coaxial cables which were phase-matched to produce a nearly uniform phase distribution across the feed cluster. Each of the 18 VPD's was calibrated before installation in the BFN and this data is used to program the BFN for the appropriate phase and amplitude across the feed cluster for a number of different antenna pattern configurations. All radiation pattern measurements described in this note were measured at 7.68 GHz, the center design frequency of the lens.

III. Single Feed Excitation

Figure 3 illustrates the measured and calculated H-plane radiation patterns with feed 35 (the fifth feed in the third row) excited. The general agreement between the two patterns is quite good. The slightly higher sidelobe level of the measured pattern is thought to be the result of a small amount of power (typically at a level of -30 to -35 dB) being "leaked" to the remaining feed elements of the BFN, a fact not taken into account in the calculated pattern. Theoretically, a -25 dB sidelobe level can increase by as much as 3.9 dB for a "leakage" power of -30 dB. For the measured pattern in

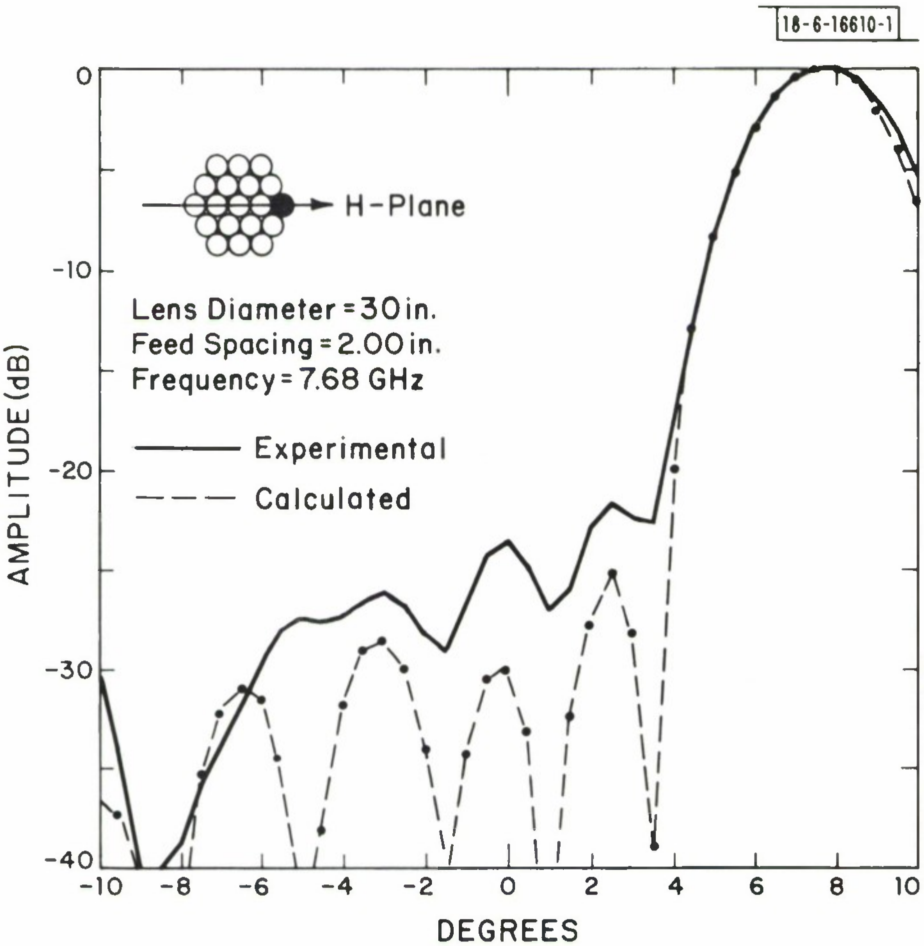

Fig. 3. Comparison of measured and calculated H-plane patterns, single feed on.

Fig. 3, the most likely feed elements contributing to the increase in sidelobe level are those in the center row (i.e., feeds 31, 32, 33 and 34) since only these feeds produce beams whose maximum gain lies in the plane of scan. If this reasoning were correct, one would expect somewhat closer agreement between the measured and calculated E-plane patterns since, in this case, there are no feeds located directly above or below feed 35. That this is true is illustrated by Fig. 4: for this case one observes much closer agreement between measured and calculated patterns. The single-beam patterns for the other feeds showed little variance from one another; the first sidelobe level averaged approximately -19 to -20 dB in the E-plane, with the sidelobe level in the H-plane lower by 3 to 4 dB.

IV. Beam Steering

Exciting two adjacent feeds with equal phase and varying the power between the two has the effect of steering the beam between the beam directions of the singly excited feeds. Figures 5-9 illustrate the excellent agreement between the normalized measured and calculated patterns when the input power to feeds 33 and 34 is varied from 0 to 1 in increments of .25. The results of the beam scanning measurements are summarized in Fig. 10 by showing the variation in gain and beam pointing direction as a function of the fractional power delivered to feeds 33 and 34. From Fig. 10 one observes that the difference between the calculated and measured beam pointing direction is less than 0.1 degree while the measured and calculated difference in gain is less than 0.5 dB.

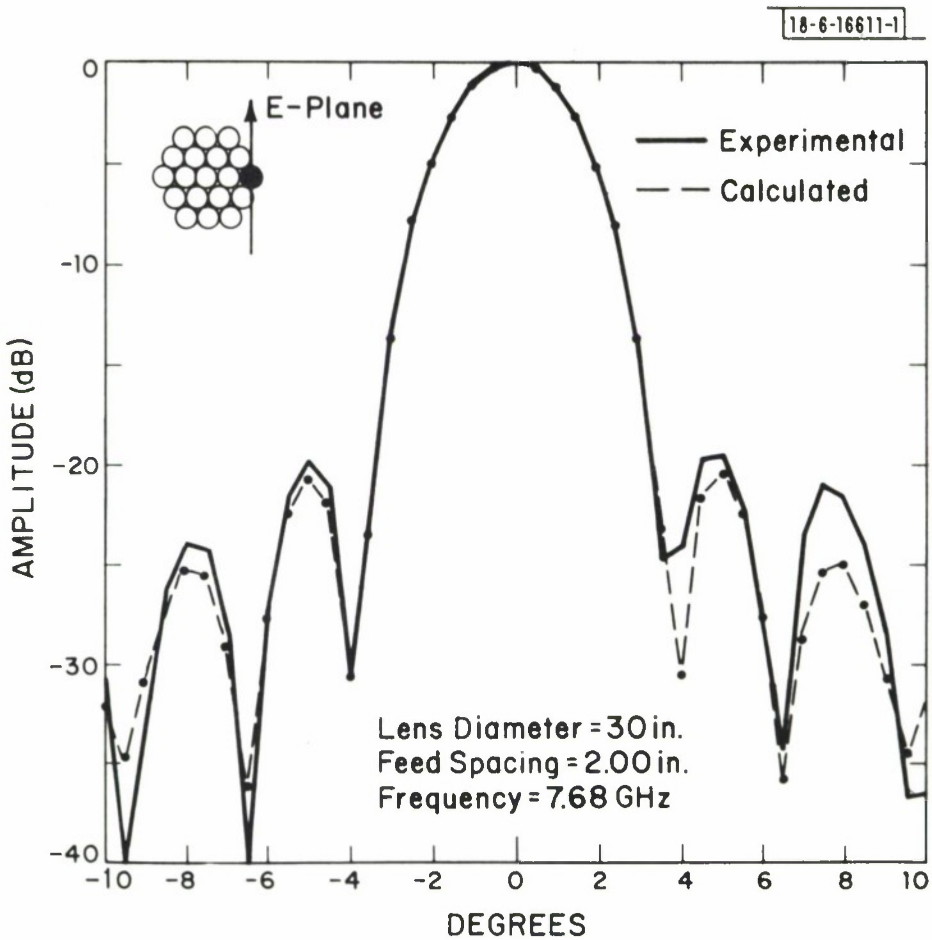

Fig. 4. Comparison of measured and calculated E-plane patterns, single feed on.

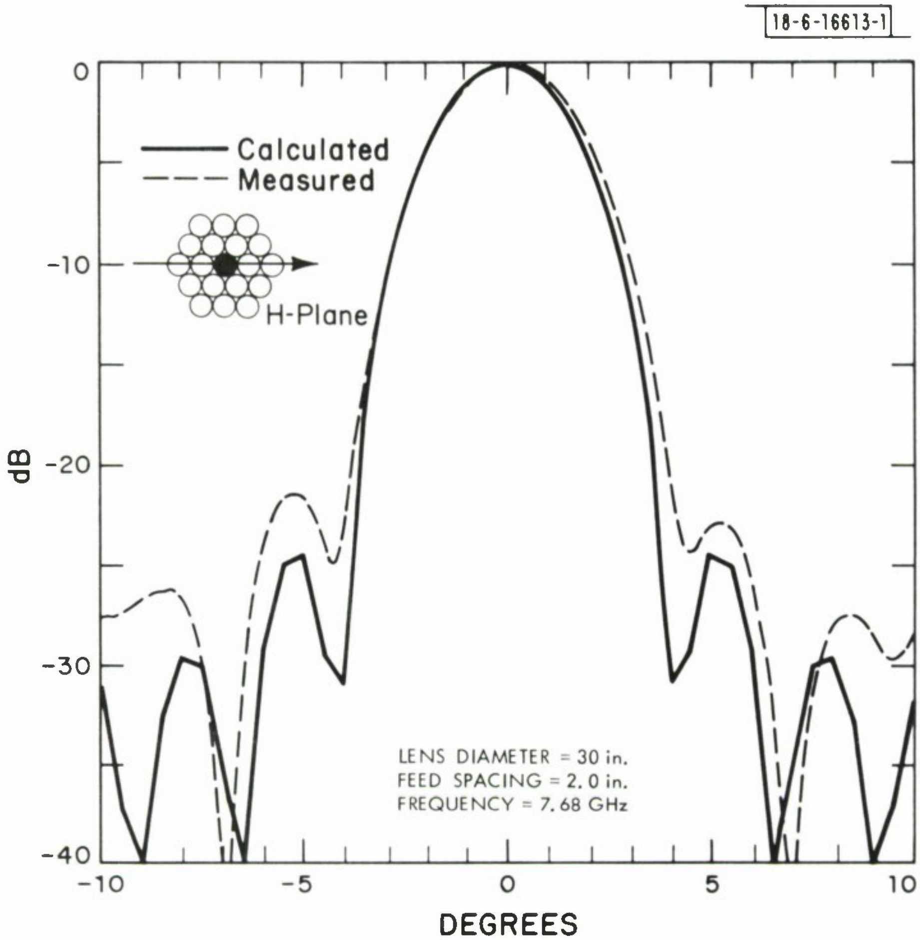

Fig. 5. Beam scanning characteristics for $P_{33} = 1.0$, $P_{34} = 0$.

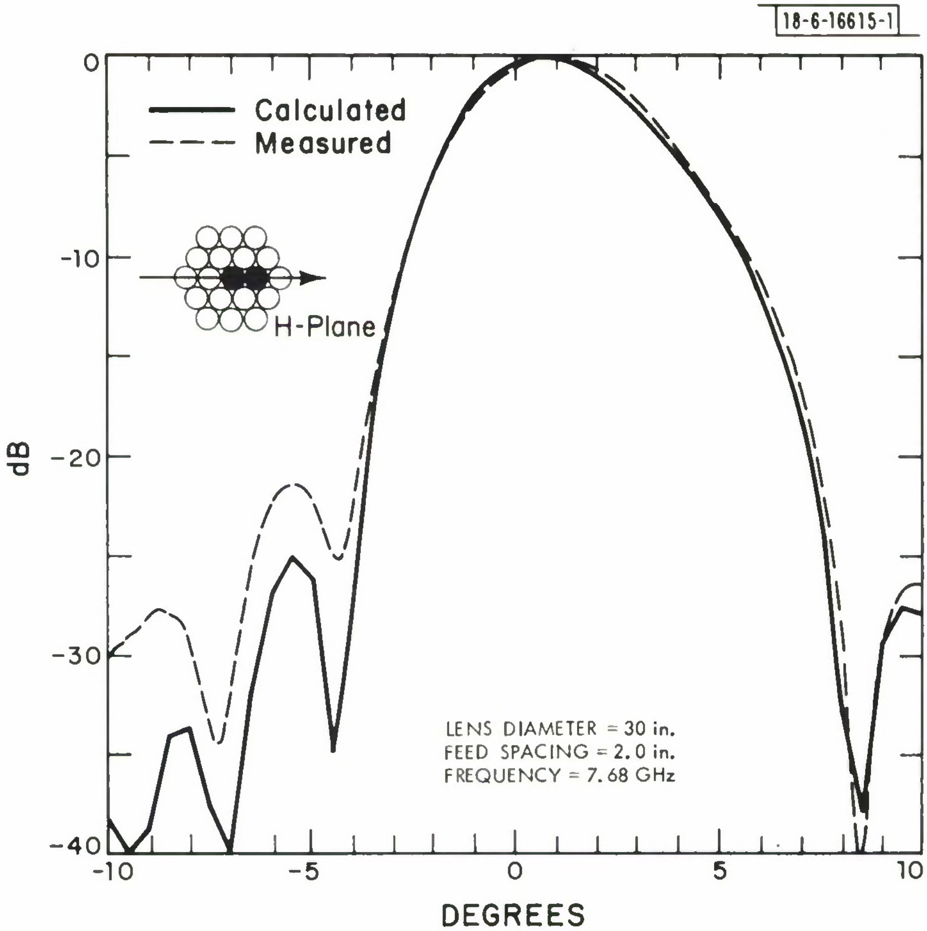

Fig. 6. Beam scanning characteristics for $P_{33} = 0.75$, $P_{34} = 0.25$.

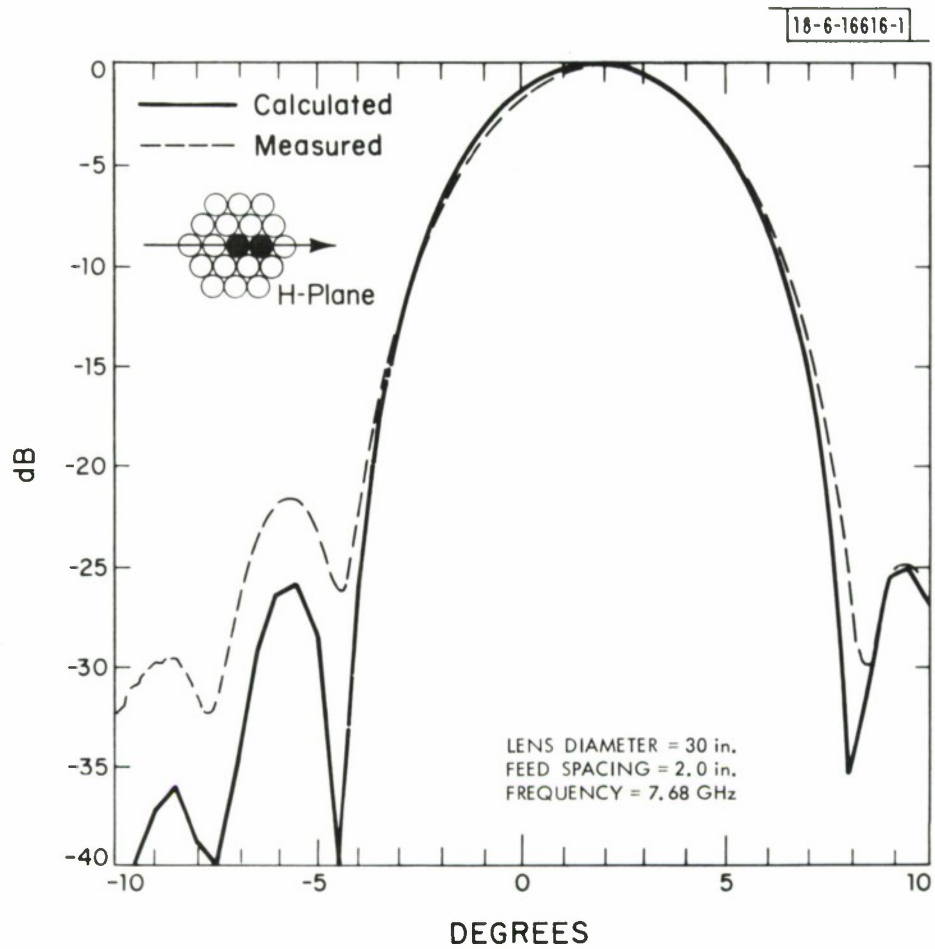

Fig. 7. Beam scanning characteristics for $P_{33} = 0.50$, $P_{34} = 0.50$.

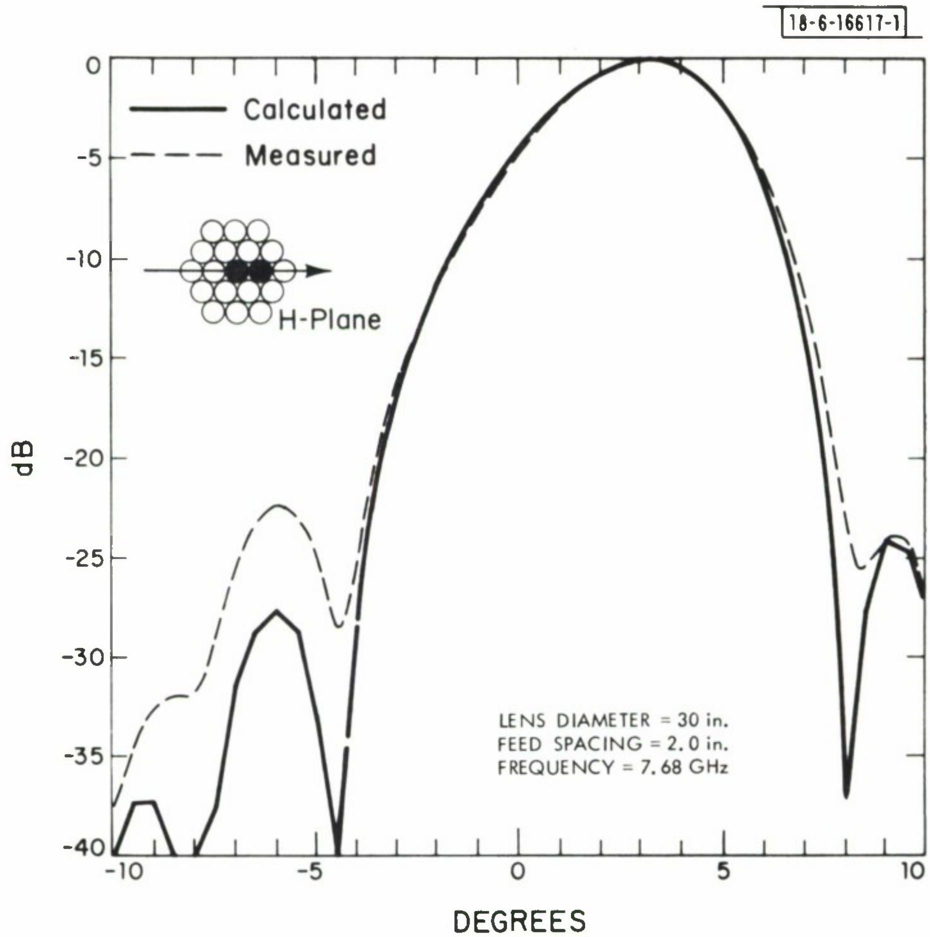

Fig. 8. Beam scanning characteristics for P_{33} = 0.25, P_{34} = 0.75.

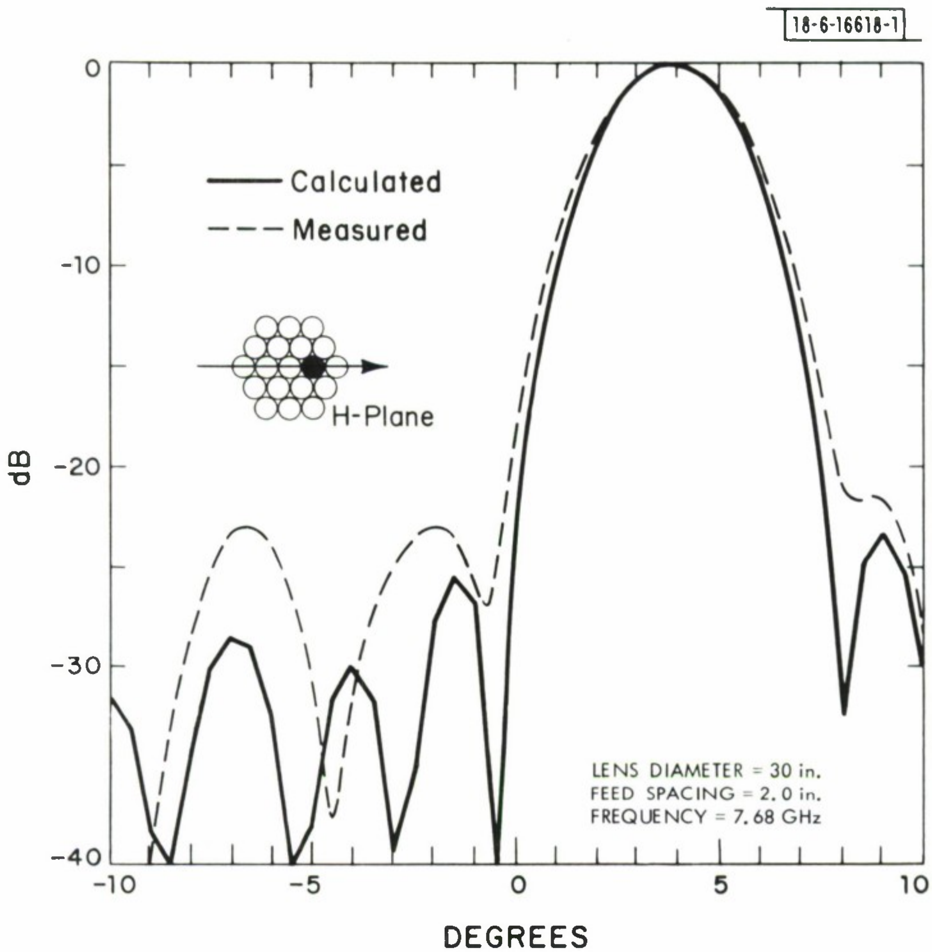

Fig. 9. Beam scanning characteristics for $P_{33} = 0$, $P_{34} = 1.0$.

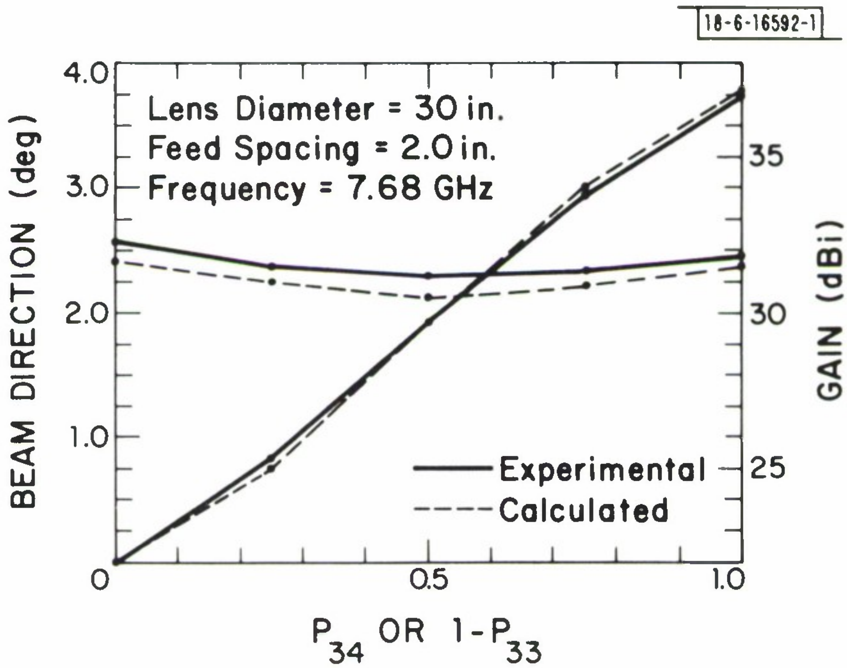

Fig. 10. Beam scanning characteristics with variable power divider (VPD) feed network.

V. Earth Coverage

A comparison of the E- and H-plane earth-coverage (EC) radiation patterns obtained with all 19 feeds excited is shown in Fig. 11. The uniformity of the feed excitation across the feed cluster was measured and found to be approximately $\pm.6$ dB and ±15 degrees. These measured feed excitations were then used to compute the calculated earth-coverage patterns as shown by the dashed curves in Fig. 11. The peak-to-peak gain ripple is approximately 2.5 dB for both the calculated and measured patterns. It is quite apparent from Fig. 11 that the 2.0-inch feed spacing is not the optimum value for producing an earth-coverage pattern as evident by the fact that the field tapers off rapidly near the edge of the 18° field-of-view (FOV). Currently measurements are in progress on a new feed cluster having a feed diameter of 2.44 inches; this diameter corresponds to the approximate feed spacing for maximizing the minimum directive gain over an 18° FOV for a 30-inch-diameter lens.

VI. Earth-Coverage with Prescribed Minima

One of the important advantages of a multiple-beam antenna results from the fact that nulls can be produced in an earth-coverage radiation pattern merely by selectively turning off those beams which come closest to the direction in which the null is desired. Figures 12 and 13 are indicative of the types of null coverage which can be obtained when either a single feed or two adjacent feeds are turned off. Figure 12 illustrates first the measured earth-coverage contour obtained with all but feed 22 excited. The area over which the power gain is reduced by at least 15 dB within the dashed 18° FOV is indicated by the small dotted region. Also shown in this figure are two dashed lines representing the calculated -6 dB and -15 dB contour lines computed

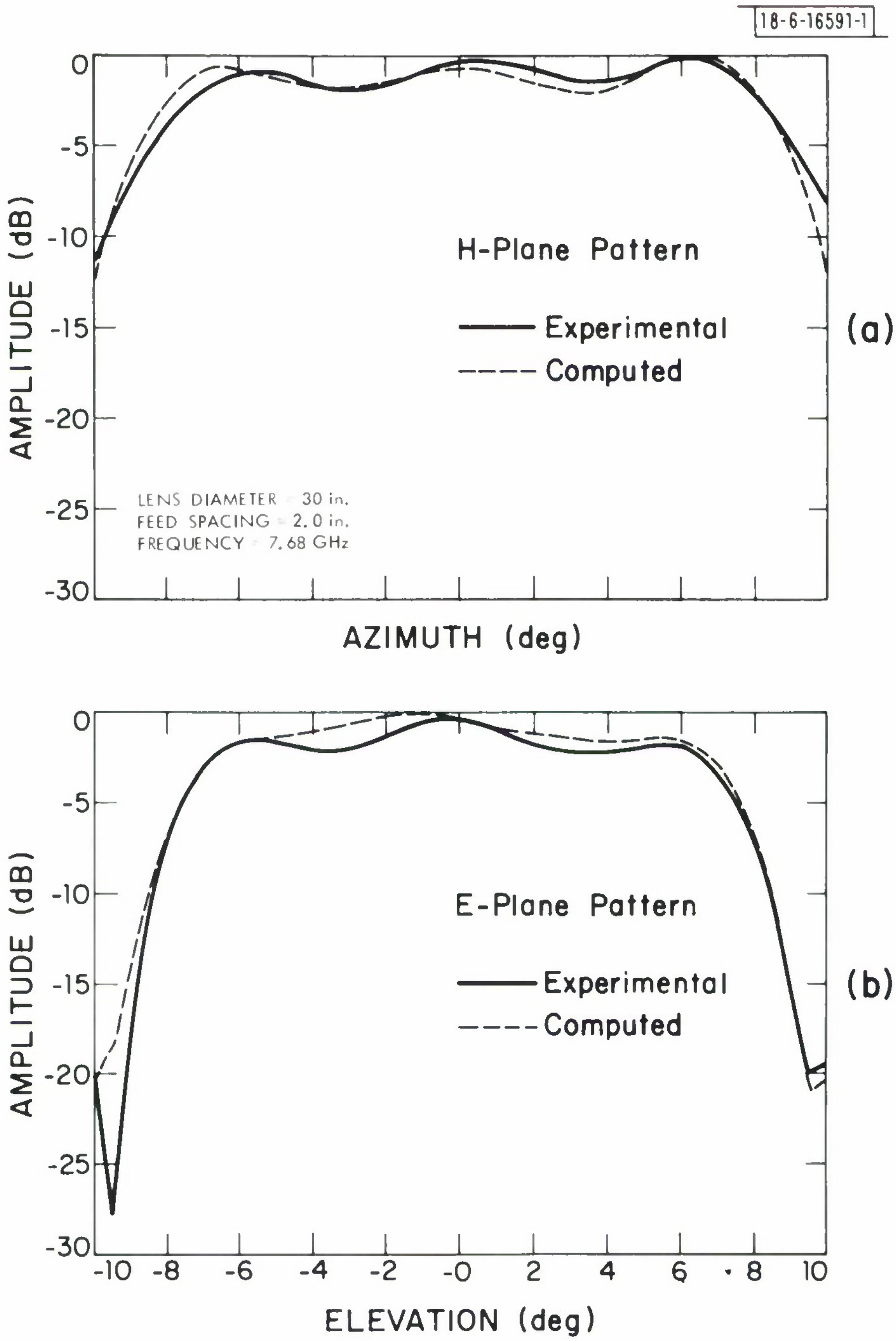

Fig. 11. Comparison of measured and computed earth-coverage patterns.

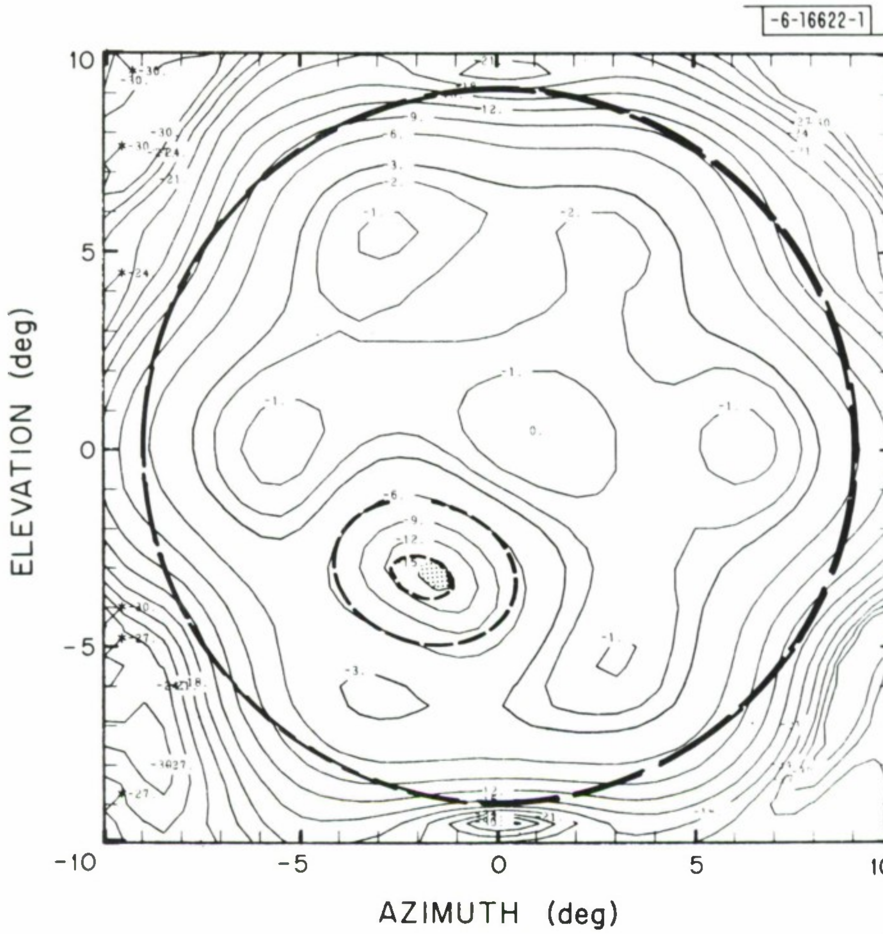

Fig. 12. Measured earth-coverage contour with feed 22 off.

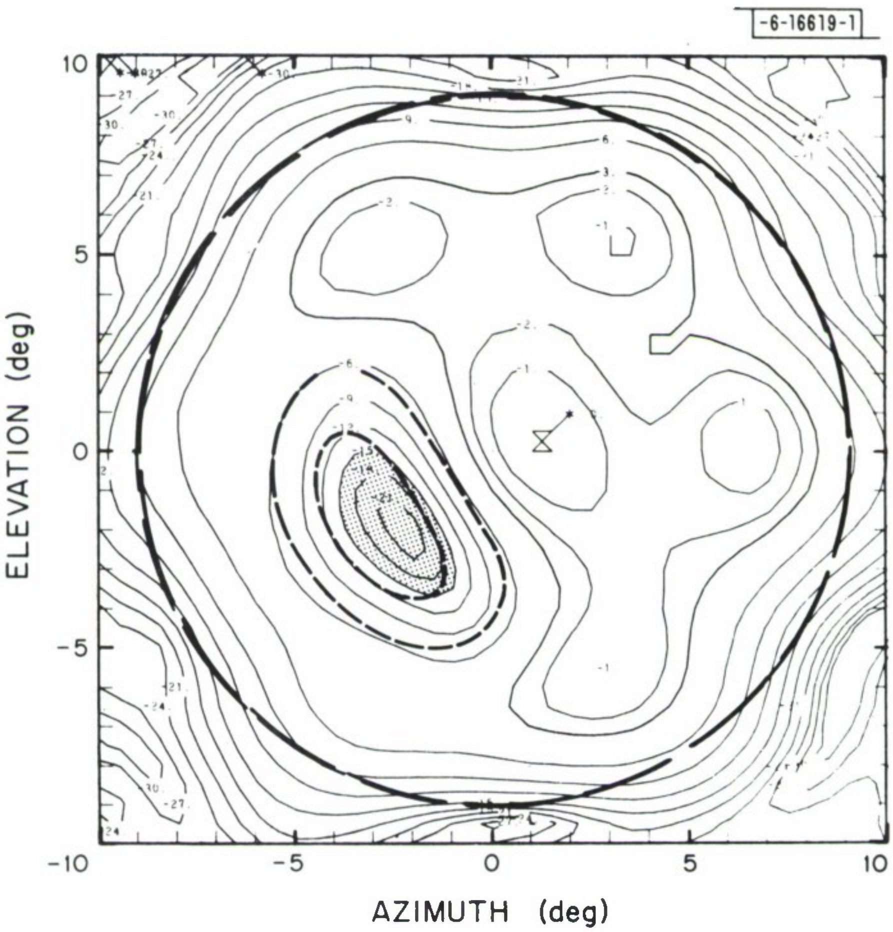

Fig. 13. Measured earth-coverage contour with feeds 22 and 32 off.

on the basis of a uniform amplitude and phase distribution across the feed cluster. The agreement between the calculated and measured -6 dB and -15 dB contours is quite good considering the fact that the measured amplitude and phase distribution across the feed cluster were $\pm$.6 dB and $\pm$ 15 degrees, respectively. In addition to excitation errors, part of the difference between the calculated and measured contours may be due to the fact that the calculated results were computed assuming an ideal, zero-tolerance lens.

Figure 13 illustrates the null coverage obtained when all but feeds 22 and 32 are excited. In this case the null level is substantially lower ($\approx$ -23 dB) than the minimum obtained with only a single feed off ($\approx$ -17 dB). However, the advantages of producing deeper nulls by turning off two beams is somewhat negated by the fact that the gain is reduced over a larger area. Comparing the areas enclosed by the measured -15 dB contour in Figs. 12 and 13, one observes nearly a tenfold increase in the coverage area when two beams are turned off, whereas the same comparison for the -6 dB contours yields approximately a twofold increase. Also shown in Fig. 13 are the calculated dashed lines representing the -6 dB and -15 dB contour levels which illustrate the very good agreement between the measured and calculated results.

VII. Gain Measurements

The computer model was used to calculate the gain of the antenna, and calculations compared with experimental results. The model includes the effects of spillover, aperture taper, reflections and zoning, as shown in Table I. Also shown in Table I is the expected performance of an ideal lens, indicating the possibility of up to a 2.6 dB increase in peak gain, if the

TABLE I

ANTENNA LOSS BUDGET

CENTER FEED EXCITED — FREQUENCY = 7.68 GHz

	CONFIGURATION	
	LES-7	IDEAL
SPILLOVER LOSS		
(Feed Gain $\simeq$ 11.2 dB; Taper $\approx$ 4.6 dB)	2.5 dB	1.5
TAPER LOSS	0.1	0.1
REFLECTION LOSS		
($\rho = \frac{1-n}{1+n}$; n = 0.64)	0.4	
ZONING LOSS	1.2	—
TOTAL LOSS	4.2	1.6
APERTURE GAIN ($4\pi A/\lambda^2$)	35.8 dB	
CALCULATED GAIN (Computer Program)	31.6	
	4.2	

antenna system could be brought closer to the ideal.

Figure 14 summarizes the results of the antenna gain measurements. The gain values in Fig. 14 have been corrected for the insertion loss of the BFN and hence represent the gain which could be obtained with a lossless BFN. Three sets of gain curves are shown in this figure; one curve for single feed excitation, one curve for earth-coverage with a single feed turned off, and one curve for earth-coverage with two and three feeds off. Associated with these curves are the three sets of scales along the bottom of the figure. Comparing first the measured and calculated results for the single beam measurements one observes that on an average the measured gain values are approximately 0.4 dB higher than the calculated values. The difference between the peak gain values for the EC measurements show a somewhat larger variance from the calculated EC directive gain values obtained on the basis of a uniform feed distribution. Part of this difference, however, is due to an approximately one dB larger peak-to-peak ripple for the measured EC pattern; this accounts for approximately 0.4 dB of the increase in the measured peak gain.

VII. Conclusions

The excellent agreement between measured and calculated data establishes a high degree of credibility in the computational technique. Thus waveguide lens antenna designs may be accurately evaluated analytically making it unnecessary to conduct an experimental investigation of their many radiation characteristics. It would be necessary only to evaluate the final design experimentally.

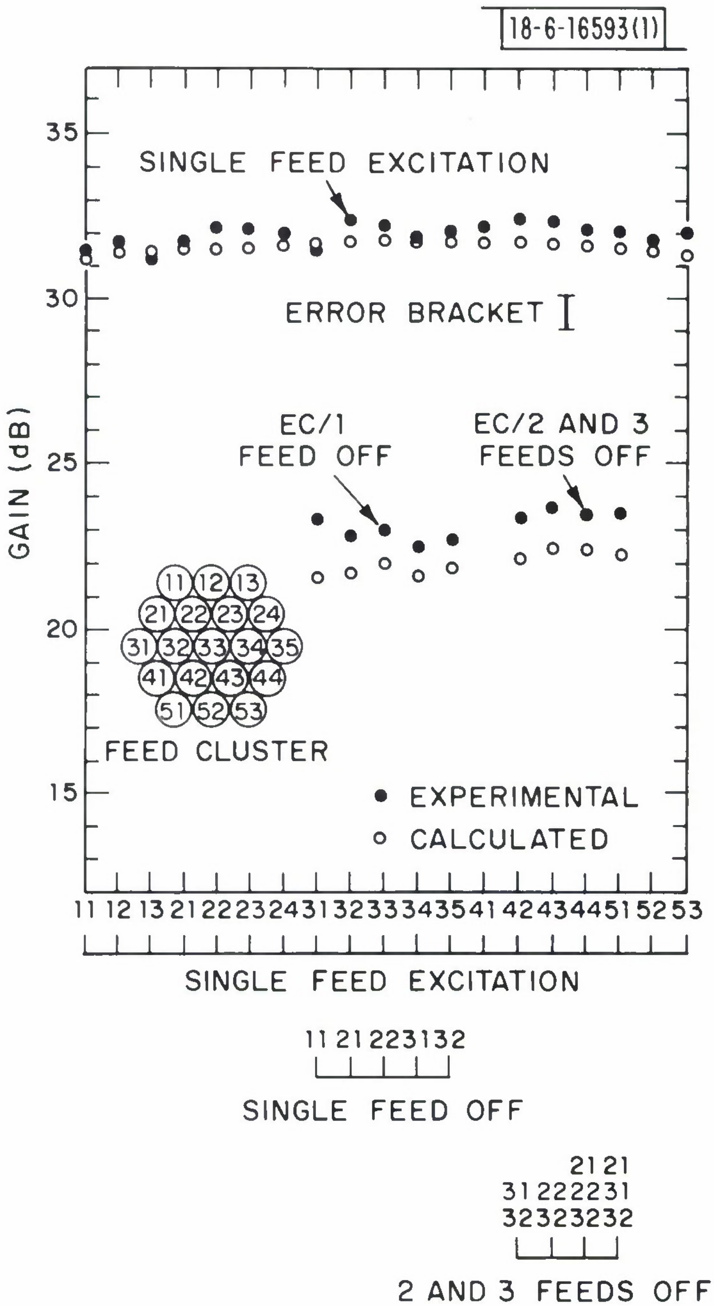

Fig. 14. Gain comparison for 30-inch diameter lens using variable power divider (VPD) feed network at f = 7.68 GHz.

The MBA system has also demonstrated the state-of-the-art of a beam-forming network using variable power dividing junctions.

Acknowledgments

The results presented in this note would not have been possible without the cooperation of Al Sanderson, Group 72, who was responsible for the mechanical design necessary for packaging the BFN into the existing lens support structure. Special appreciation is extended to Bob Burns and Don Newcomb of the Antenna Test Range for their assistance in performing the measurements and finally to Tim Turbett for writing the computer programs necessary for processing the measurement data.

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1. A. R. Dion and L. J. Ricardi, "A Variable-Coverage Satellite Antenna System, Proc. IEEE 59, 252-262. (1971), DDC AD-728190.

2. L. J. Ricardi, *et al.*, "Some Characteristics of a Communication Satellite Multiple-Beam Antenna," Technical Note 1975-3, Lincoln Laboratory, M.I.T. (28 January 1975), DDC AD-A006405.

3. A. R. Dion, "Optimization of a Communication Sattellite Multiple-Beam Antenna," Technical Note 1975-39, Lincoln Laboratory, M.I.T. (27 May 1975), in press.

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

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